TURNING CO_2 INTO VALUE

FUELS & CHEMICALS FROM SOLAR ENERGY | THE PHOTO2FUEL JOURNEY

6 AUGUST 2025

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Conjugated Polymer-Engineered Biohybrid Systems for Regulating Biosynthesis

Institute of Chemistry, Chinese Academy of Sciences
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Haotian Bai

Educational Background

•2008–2012
B.S. in Chemistry, College of Chemistry and Chemical Engineering, Hunan University
Advisor: Prof. Jianhui Jiang

•2012–2017
Ph.D. in Organic Chemistry, Institute of Chemistry, Chinese Academy of Sciences (ICCAS)
Advisor: Prof. Shu Wang

Professional Experience

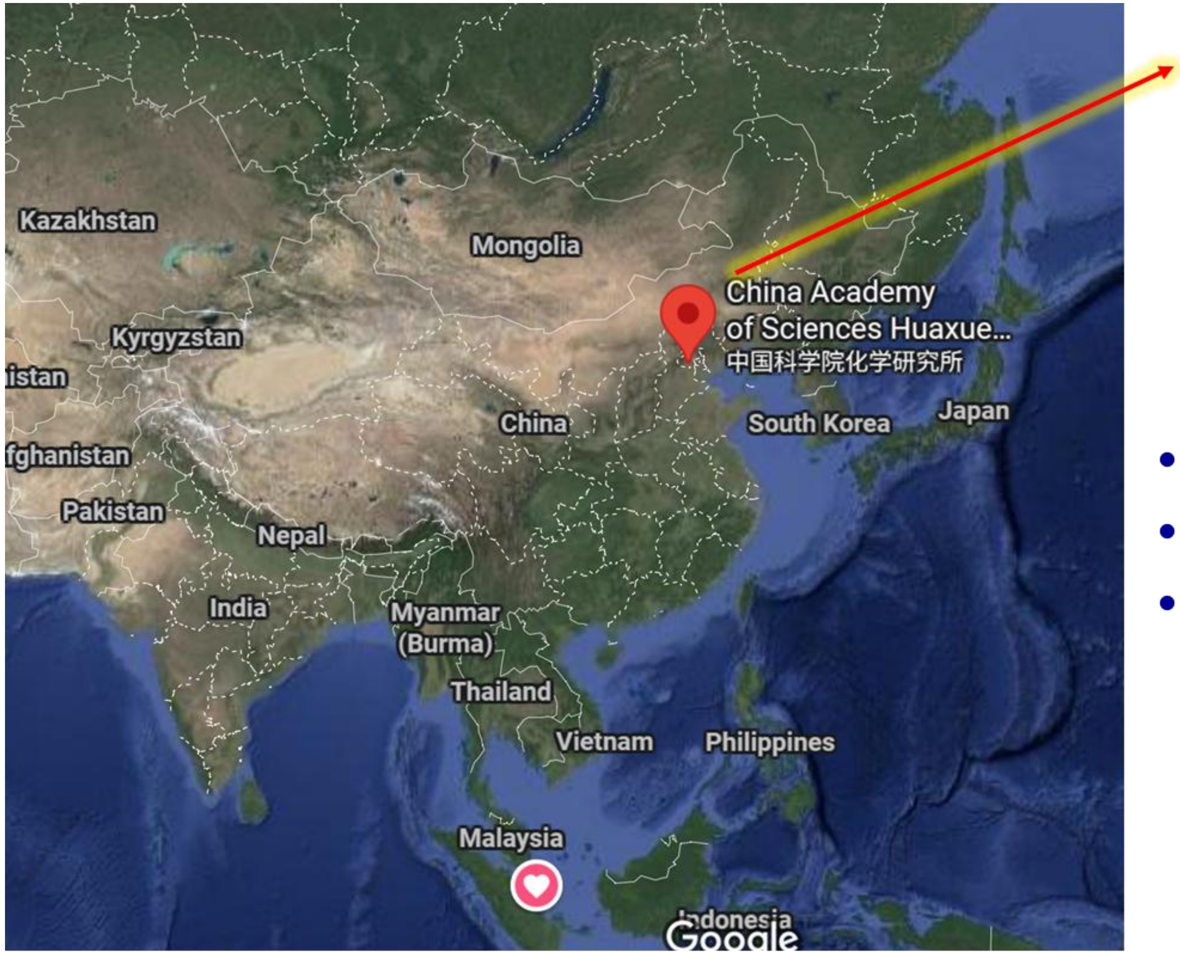
•2017–2018
Postdoctoral Fellow, Department of Chemistry and Biochemistry, University of California, Los Angeles (UCLA)
Advisor: Prof. Yunfeng Lu

•2018–2021
Postdoctoral Fellow, Department of Chemistry and Chemical Engineering, The Hong Kong University of Science and Technology (HKUST)
Advisor: Academician Ben Zhong Tang

•2021–Present
Professor, ICCAS




Institute of Chemistry, Chinese Academy of Sciences (ICCAS)



Beijing (北京)

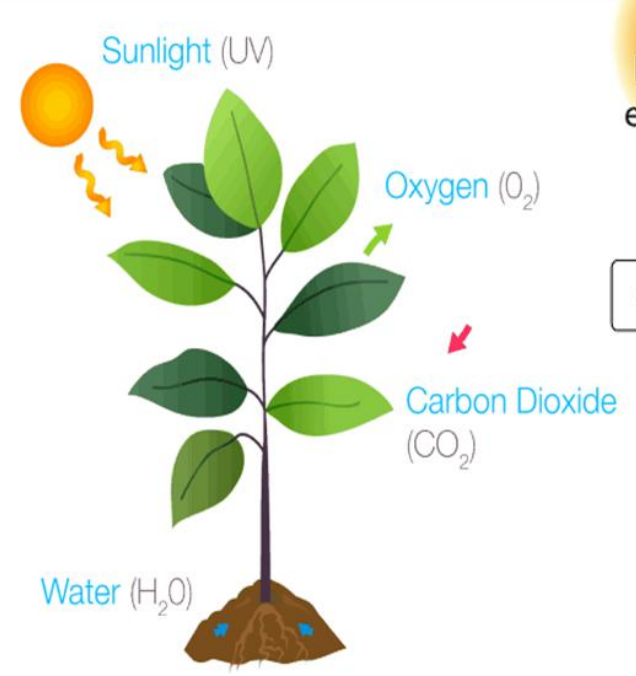
ICCAS

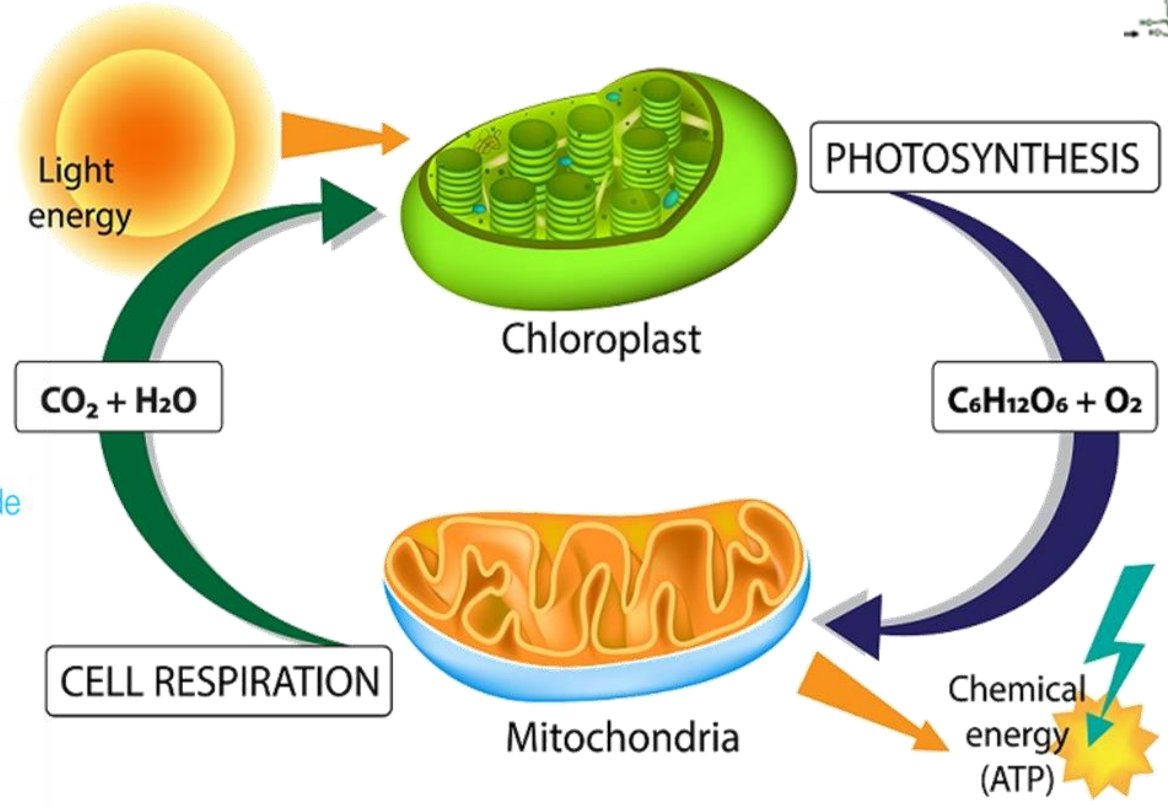
- **Founded in 1956**
- **Celebrates its 70th anniversary next year**
- **The only comprehensive research institute in the field of chemistry under CAS**

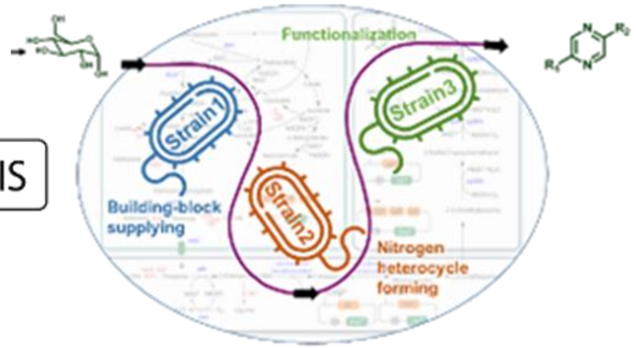
Molecular and Nano sciences	Organic/ Polymer Materials	Chemical Biology	Energy and Green Chemistry	Advanced Materials

Background

Foundational source sustaining all life on Earth

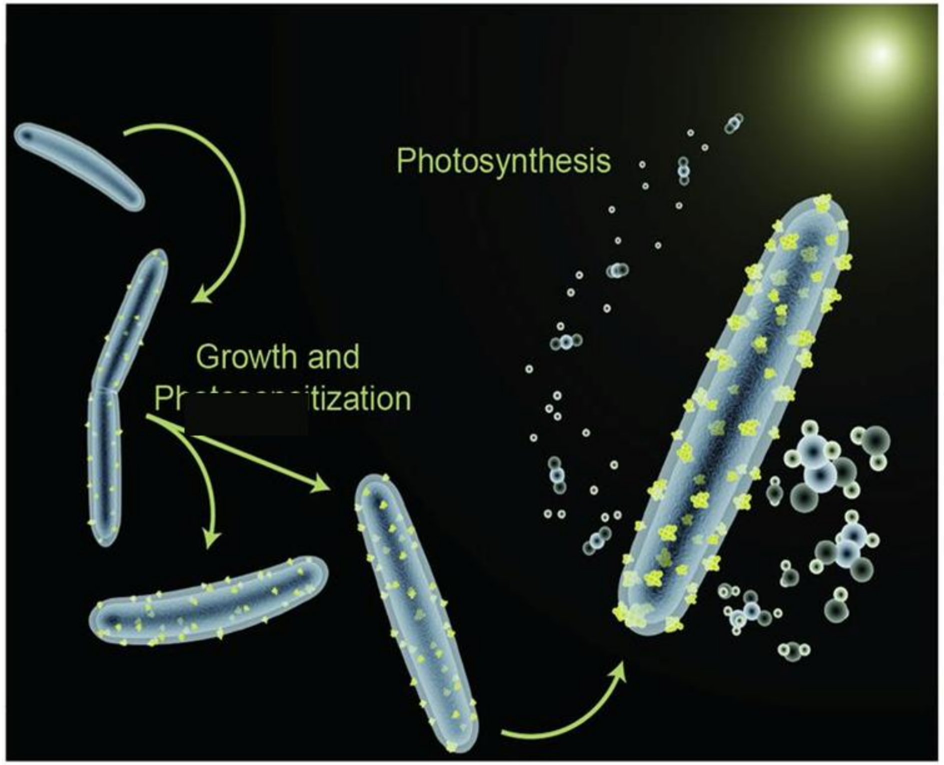




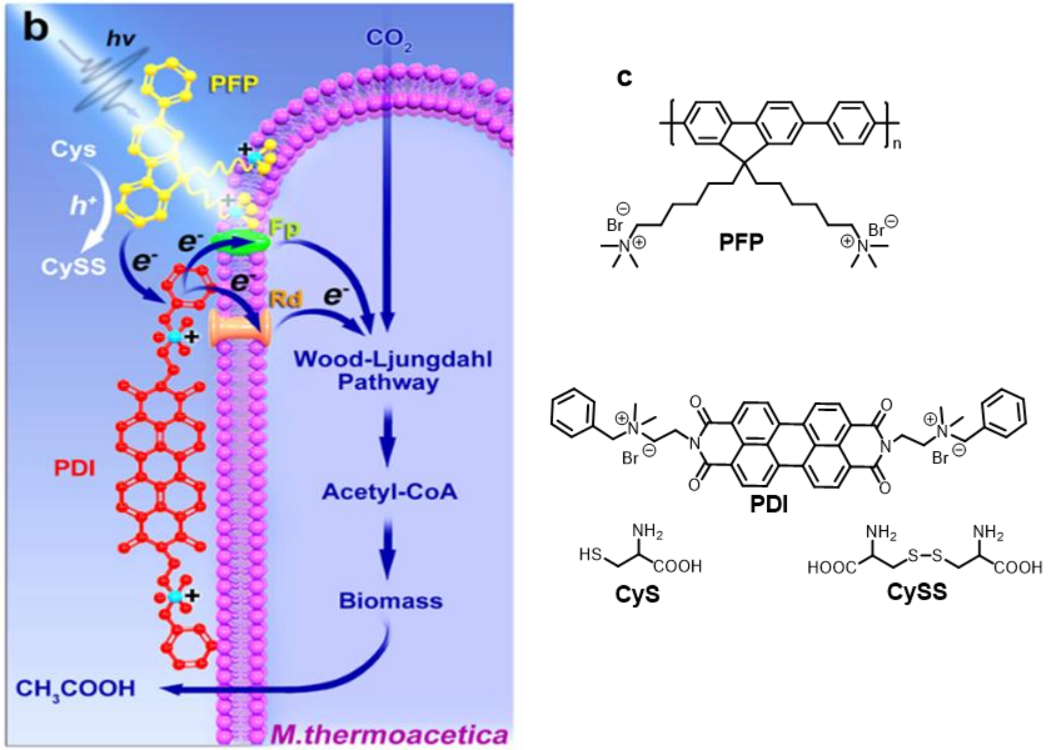


- ➢ Biosynthesis: transform organic matter into energy and valuable chemicals

Artificial Photosynthetic Biohybrids is a Viable Way



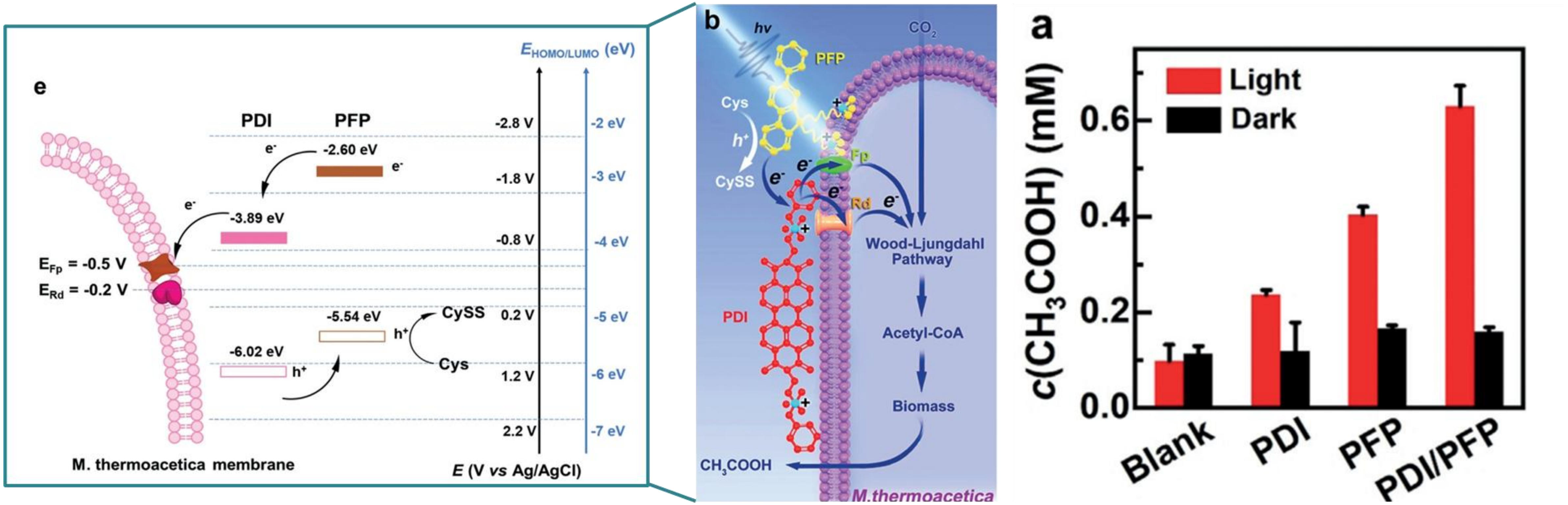
P. D. Yang, et al. ***Science***, 2016, 351, 74-77.



S. Wang et al. ***Angew. Chem. Int. Ed.*** 2020, 59, 7224-7229.

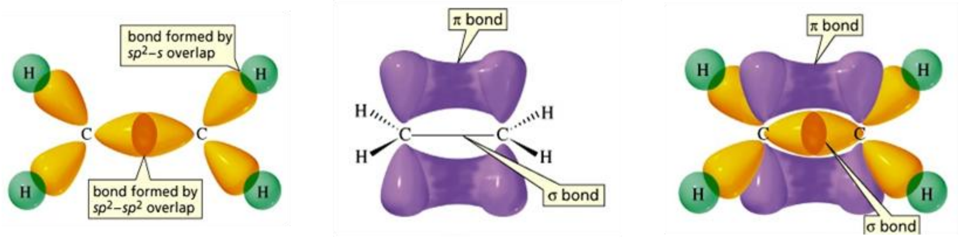
- **Photosensitizer combined with non-photosynthetic microorganisms**
- **Active the W-L pathway and Convert CO2 to CH3COOH under white light**

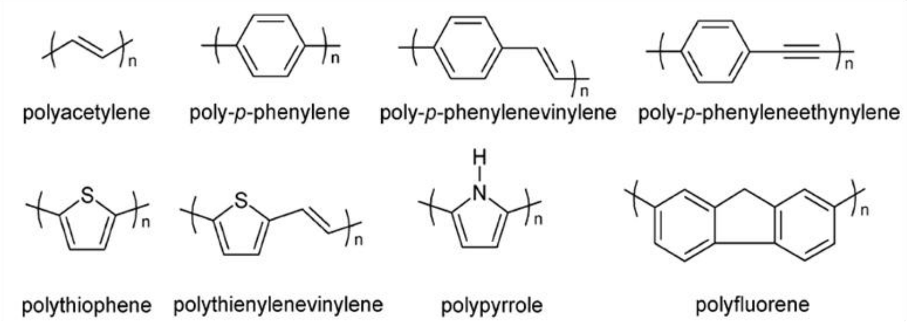
Key factors in the hybrid systems (Biological foundation)



1. Light energy capture and Photo-induced electrons （Materials）
2. Electron transfer (From material to bacteria)
3. Specific pathway activation （Biosynthesis）

Our Tools: Conjugated polymers





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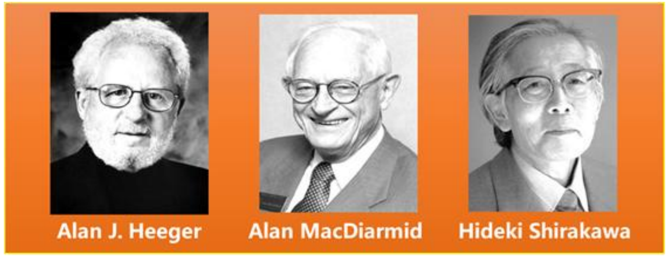
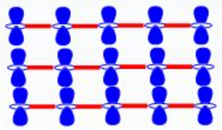


Synthesis, modification, doping →



→ Semiconducting

Light-activated →

→ Photoluminescence

Photo-induced electron transfer (PET) →

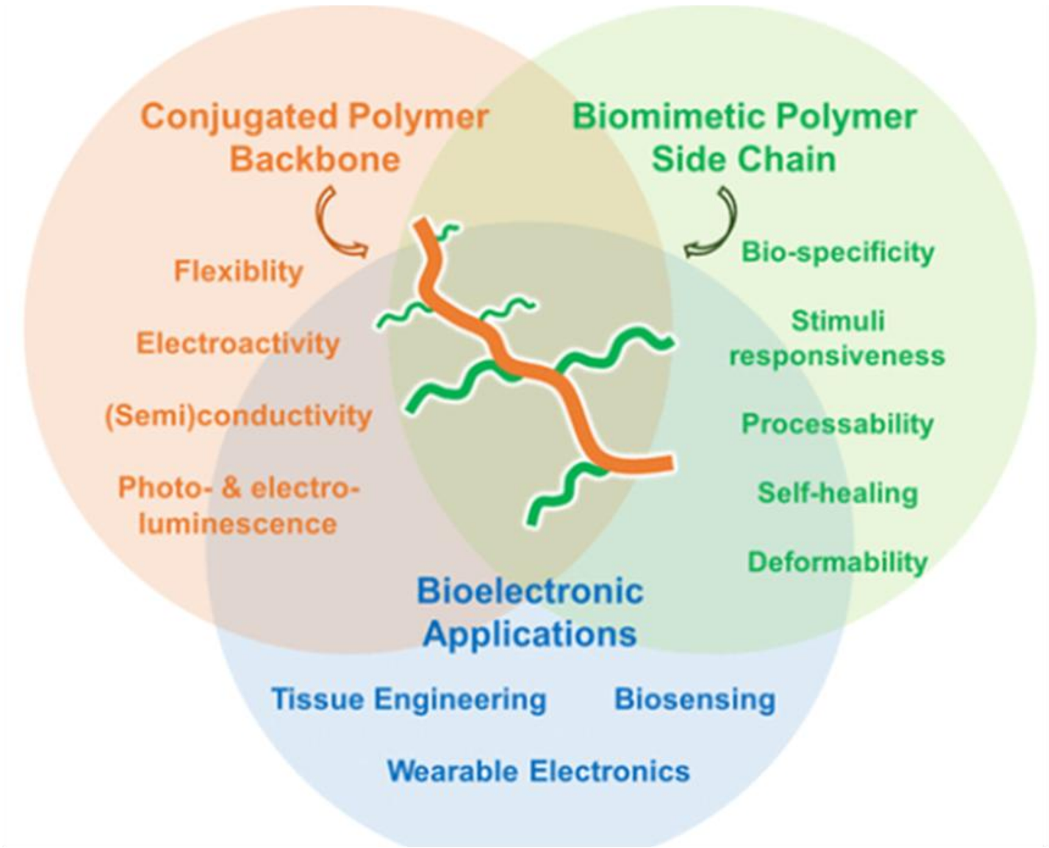
LUMO Acceptor
HOMO Donor

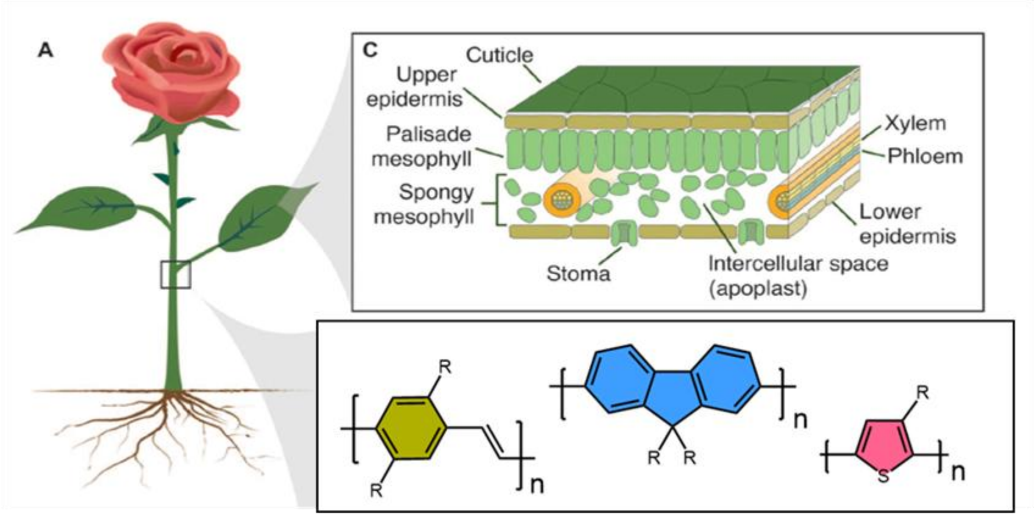
→ Photoelectricity & Photovoltaic

➢ **Conjugated polymers are organic macromolecules with alternating single and double bonds, forming a continuous system of overlapping p-orbitals throughout the polymer chain.**

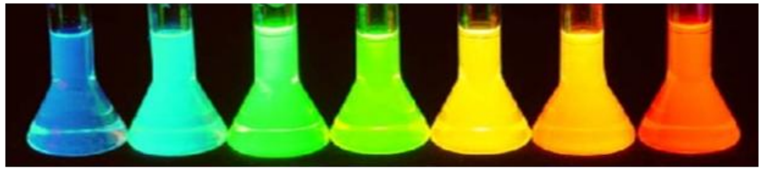
C. Zhu, S. Wang*, et al., ***Chem. Rev.***, 2012, 112, 4687-4735; L. Feng, S. Wang*, et al. ,***Chem. Soc. Rev.*** , 2013, 42, 6620-6633

Conjugated polymers：Ideal Biological Interface materials





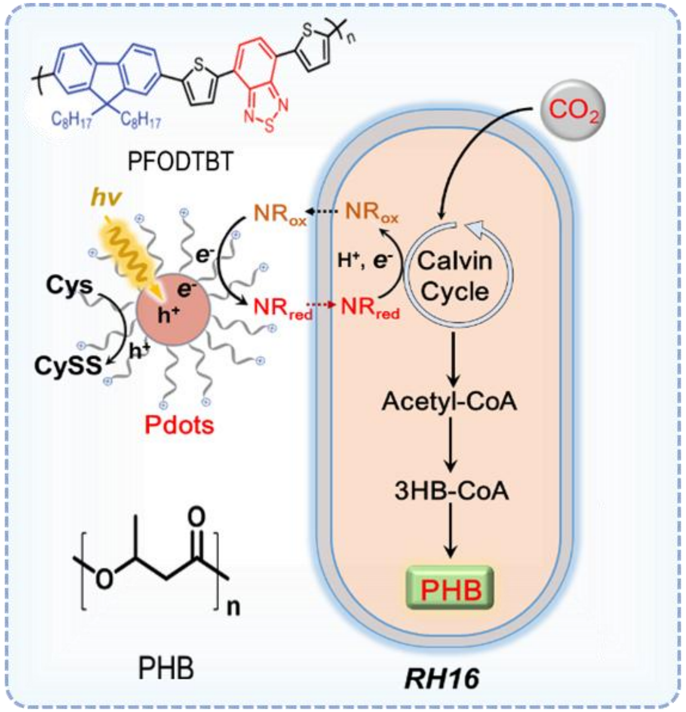
- **Water dispersibility/solubility**
- **Good biocompatibility**
- **High fluorescence quantum yield**
- **Bio-conductivity**

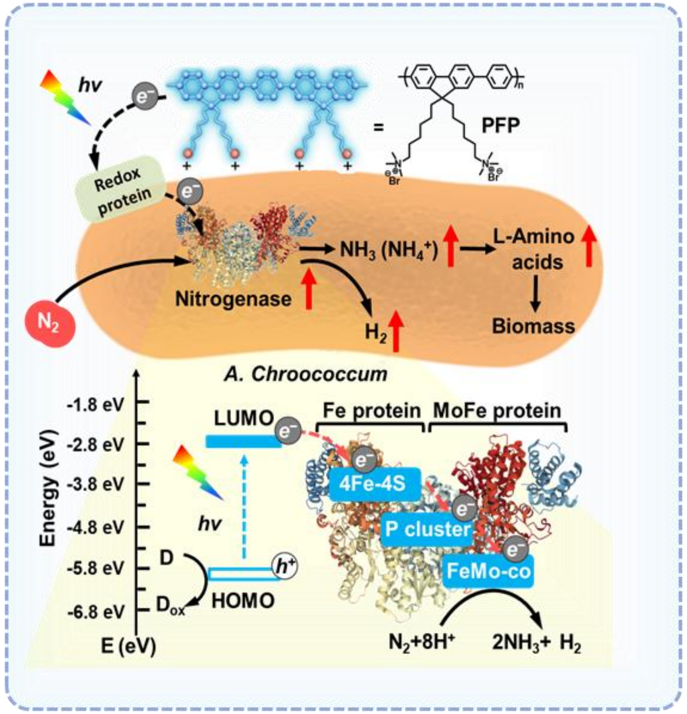


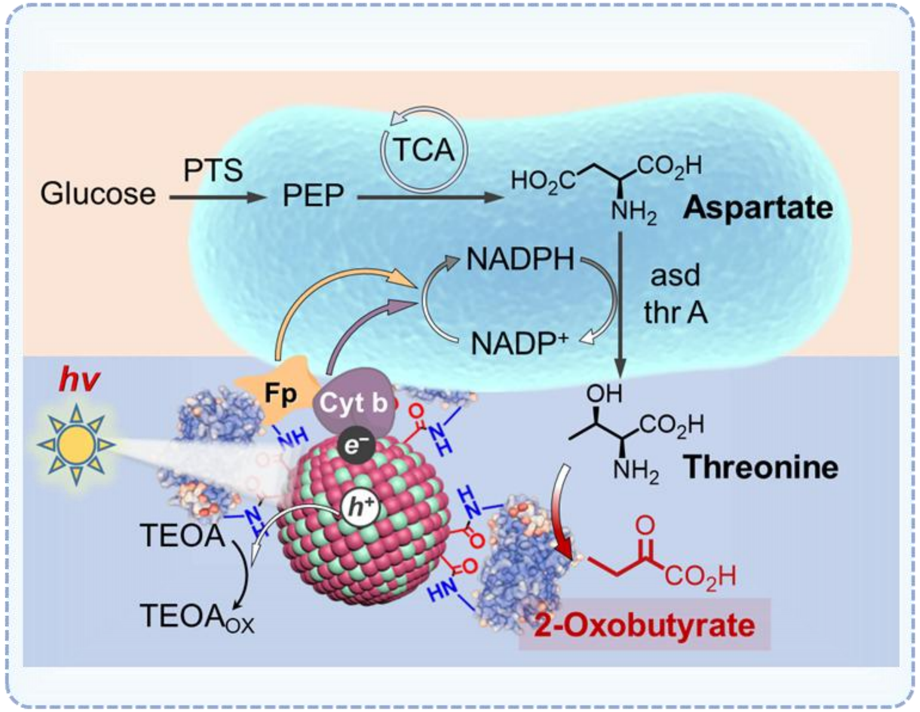
C. Zhu, S. Wang*, et al., ***Chem. Rev.***, 2012, 112, 4687-4735； L. Zhou, S. Wang*, et al., ***Acc. Chem. Res.*** , 2019, 52, 3211-3222; E. Stavrinidou, R. Gabrielsson*, E. Gomez*, et al, ***Sci. Adv***, 2015, 1: e150113.

Artificial Photosynthetic Biohybrids：

Photosensitizer combined with non-photosynthetic microorganisms







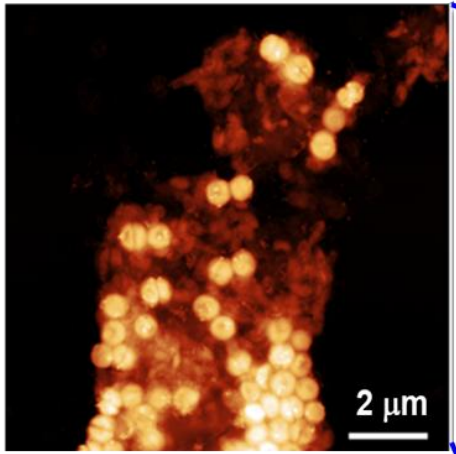
◆ **Active the Calvin Cycle for CO2-Fixing**

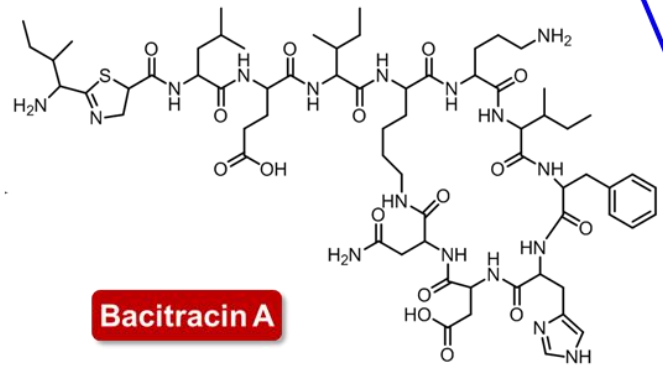
◆ **Active the Nitrogenase for N2-Fixing**

◆ **CP-based NPs for photosynthesizing threonine and 2-Oxobutyate**

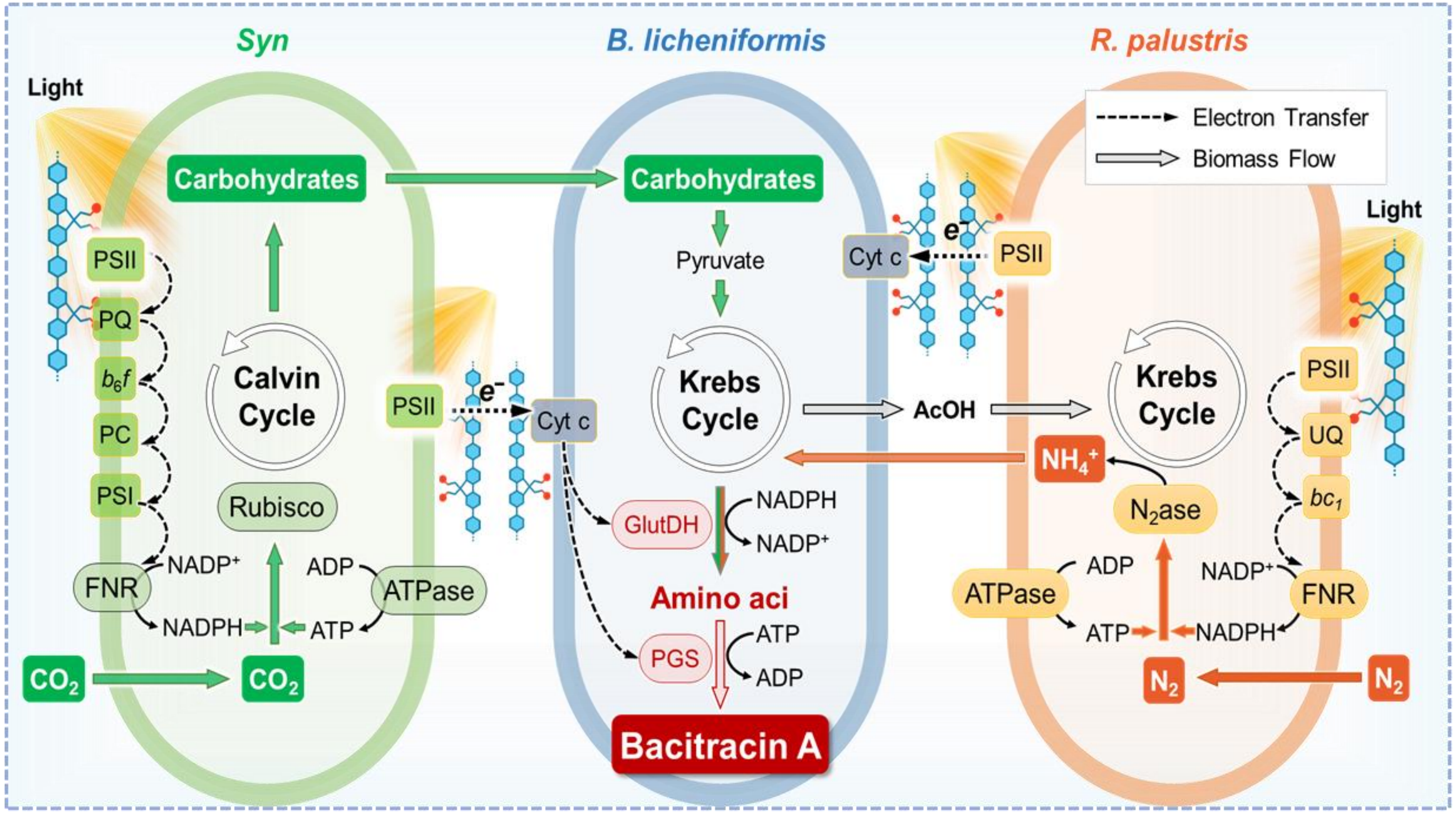
W. Yu, **H. Bai***, S. Wang*, ***ACS Appl. Mater. Interfaces*** 2023, 15, 2183−2191; Y. Zeng, **H. Bai***, G. C. Bazan, *S. Wang*, et al, ***Angew. Chem. Int. Ed.*** 2023, e202303877; W. Yu, **H. Bai*,** S. Wang*, et al, ***Research*** 2022, 9834093; W. Chen, **H. Bai*,** S. Wang*, et al, ***ACS Appl. Mater. Interfaces*** 2024, 16, 16, 19914–19925

Solar-powered Multi-organism Symbiont Mimic System





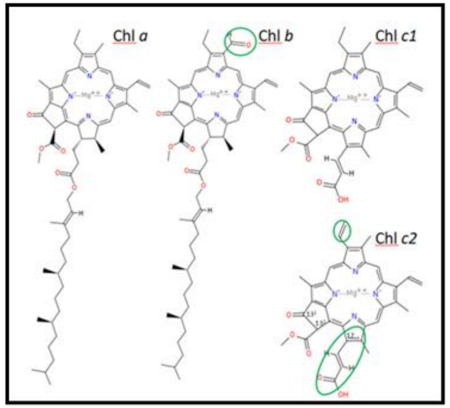
Bacitracin A

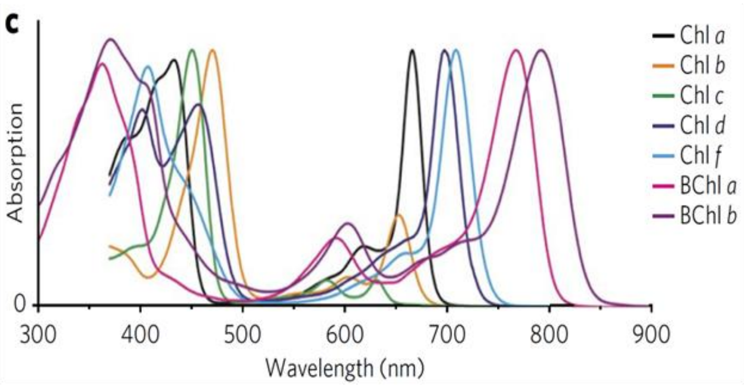


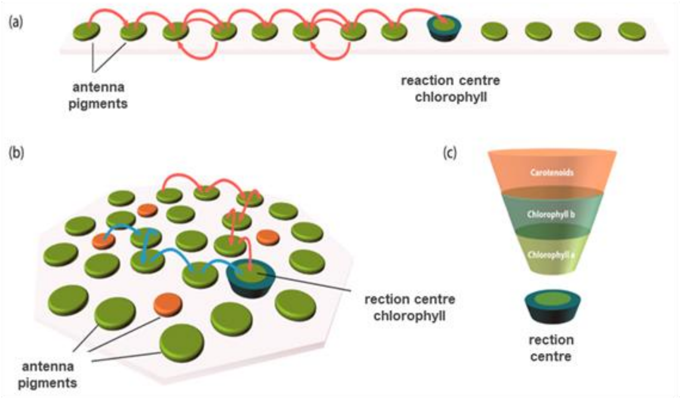
- **Polypeptides synthesis (Bacitracin A and Polyglutamic acid), CO_2 and N_2 as carbon and nitrogen**
- **Polypeptides synthesis, relying on enhanced direct interspecific substance and electron transfer**

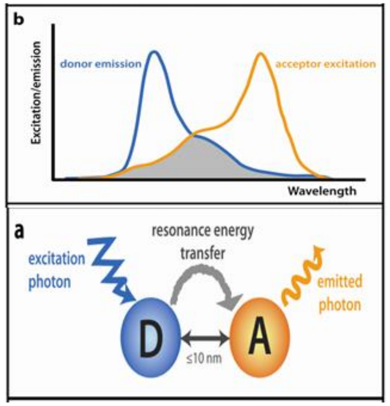
W. Yu, **H. Bai***, S. Wang*, et al., ***Sci. Adv.***, 2023, 9, eadf6772.

Photosynthesis: Enhanced Light Capture and Energy Conversation

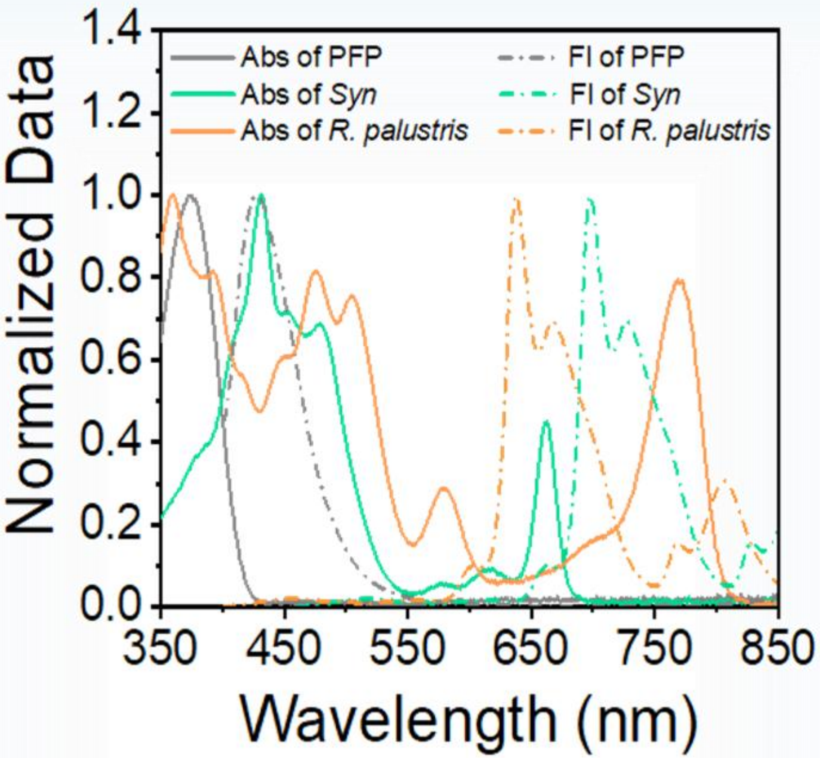






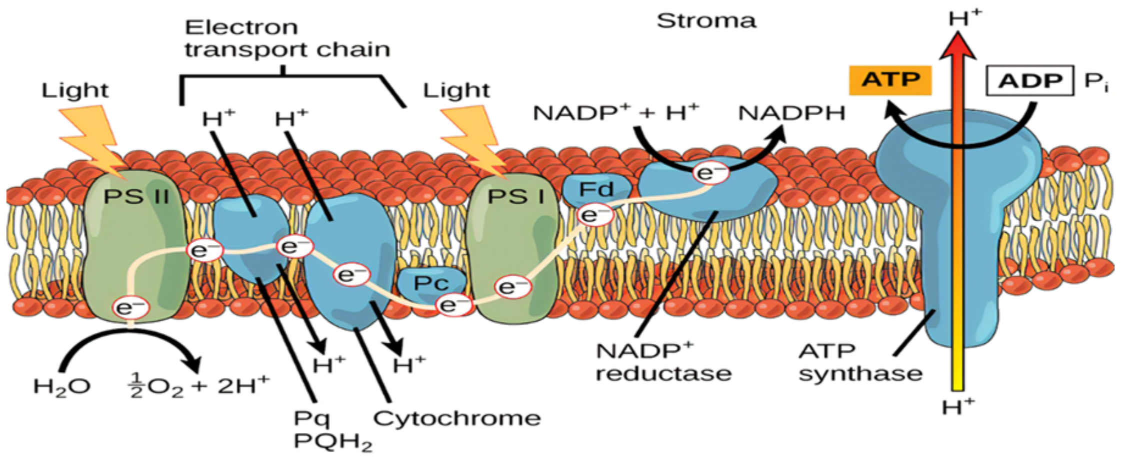


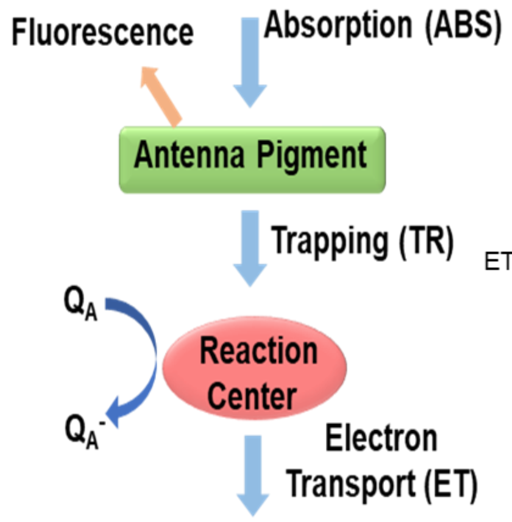
- **Chlorophyll and other pigments in the chloroplasts capture the light energy and use it to drive the conversion.**

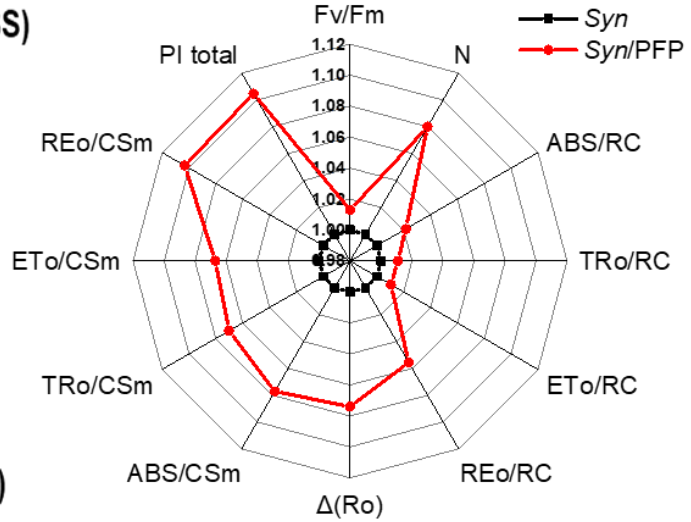


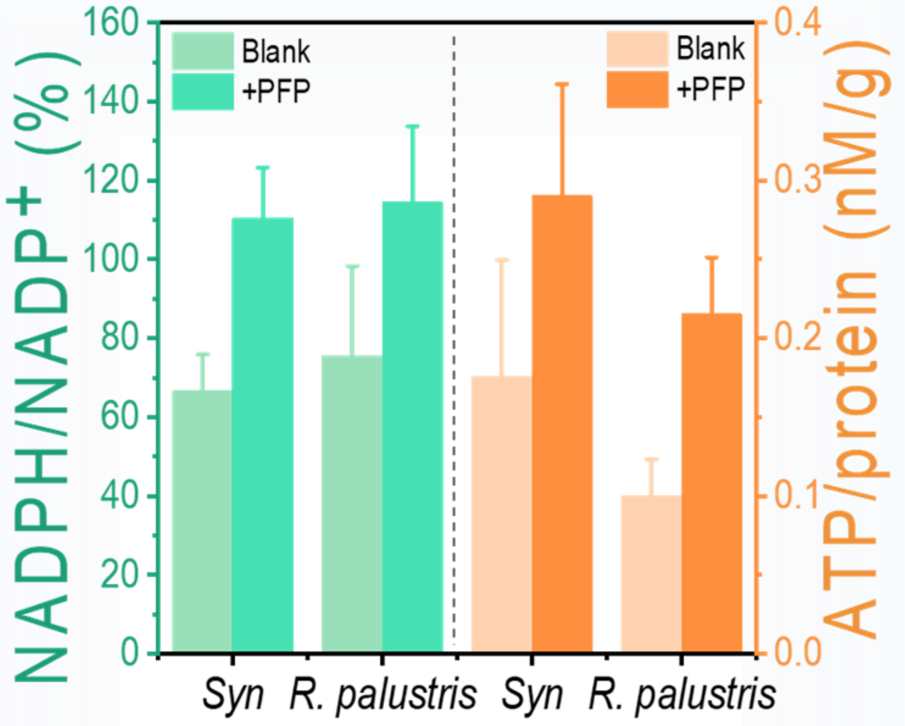
- **PFP can help photosynthetic units with a wider range of light energy collection and conversion.**

Photosynthesis: Enhanced Light Capture and Energy Conversation



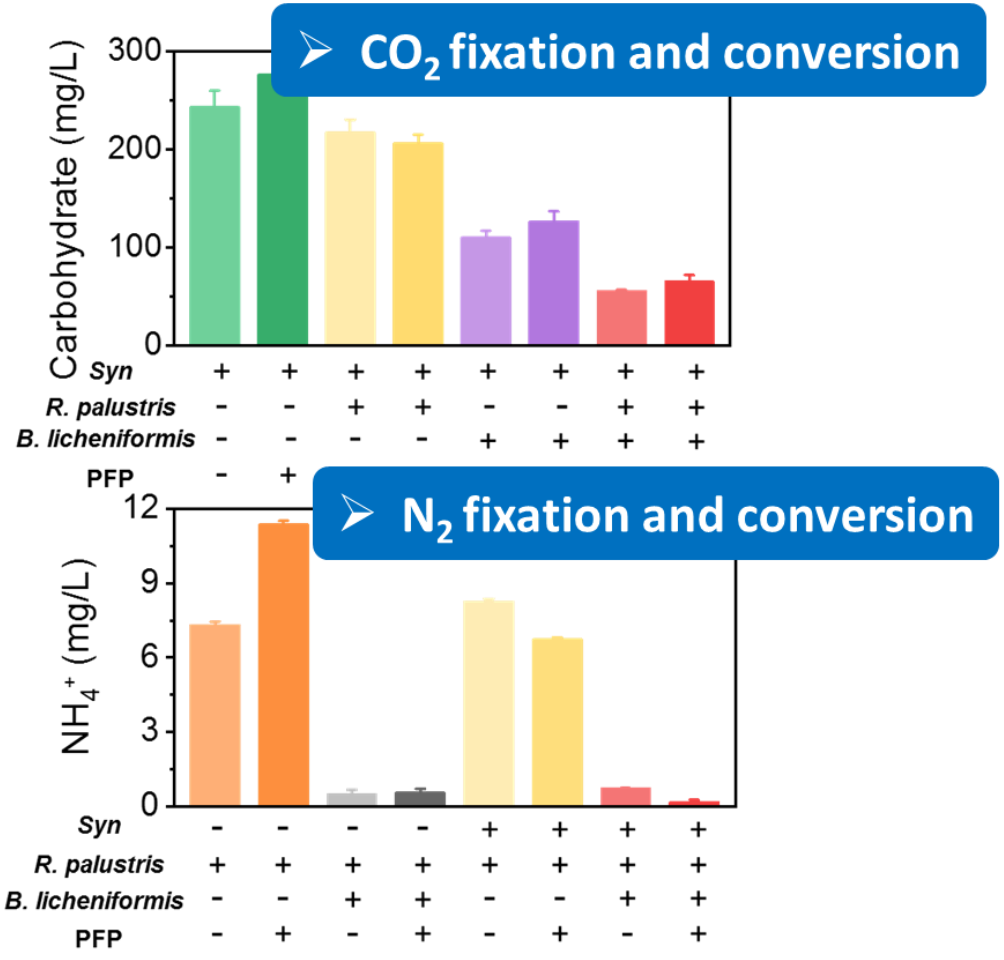




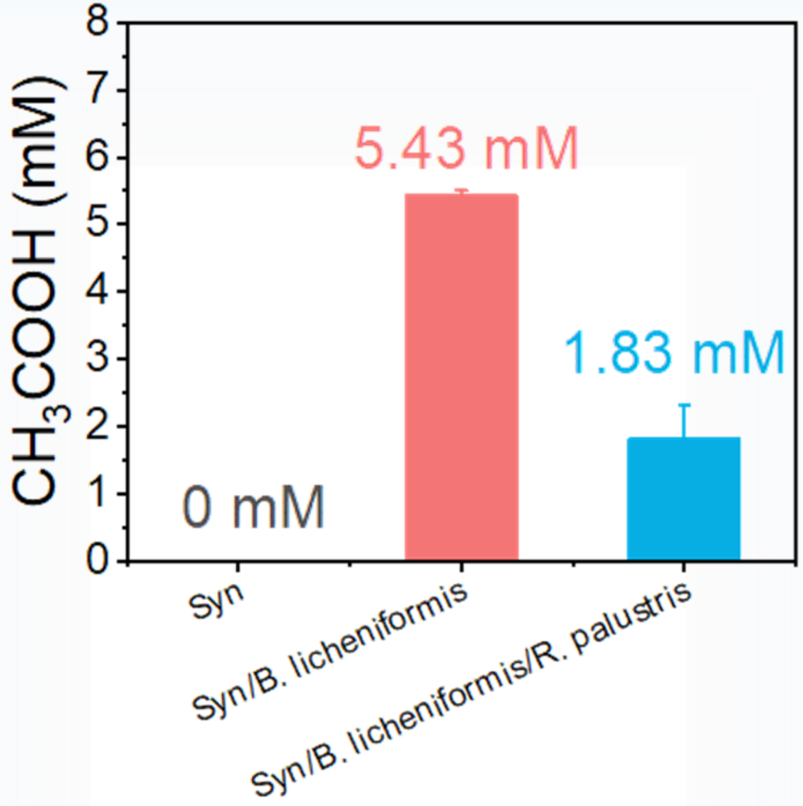


- **PFP increased NADPH/NADP+ and ATP**
- **Syn: 66% and 65%**
- **R. palustris: 52% and 115%**

Improved the Products Exchange and Utilization Between Cells



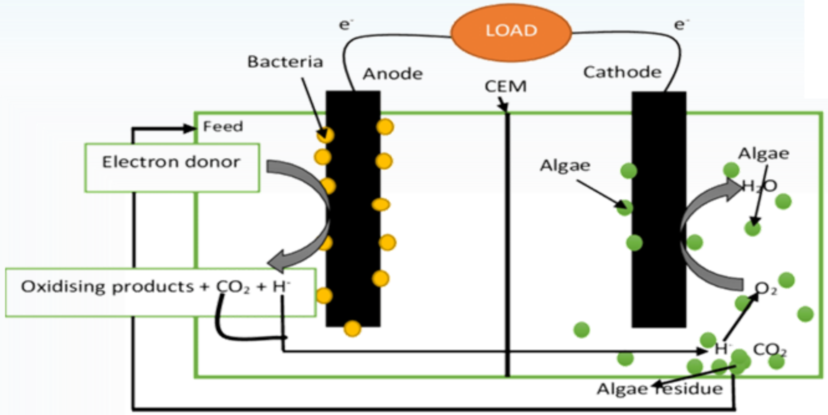
● **Improved carbohydrate and ammonium generation and utilization inside B. licheniformis**

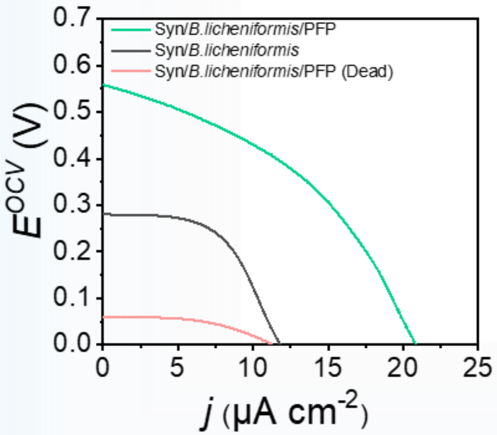


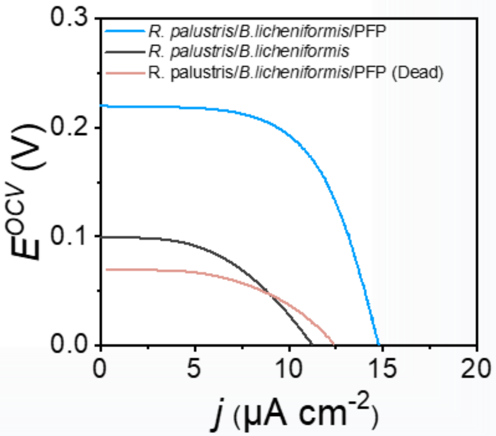
➢ **By-products (acetic acid) of B. licheniformis can be used by R. palustris**

Intercellular Directed Electron Transfer and Injection：

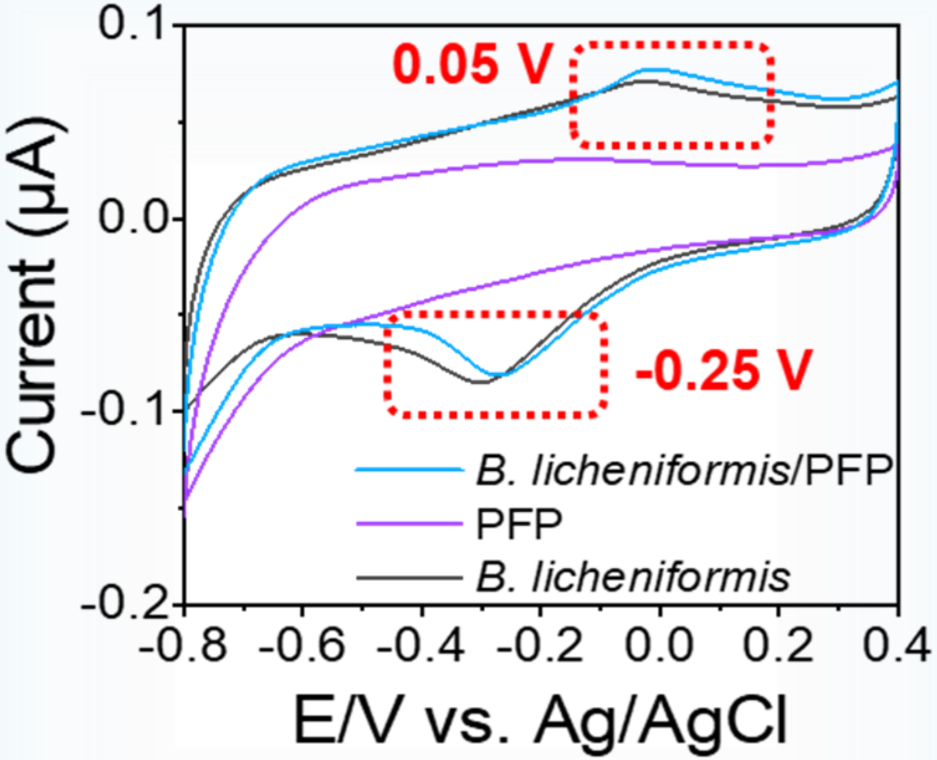
From CO2 and N2 Fixation Modules (Syn and R. palustris) to Biosynthetic Modules (B. licheniformis)





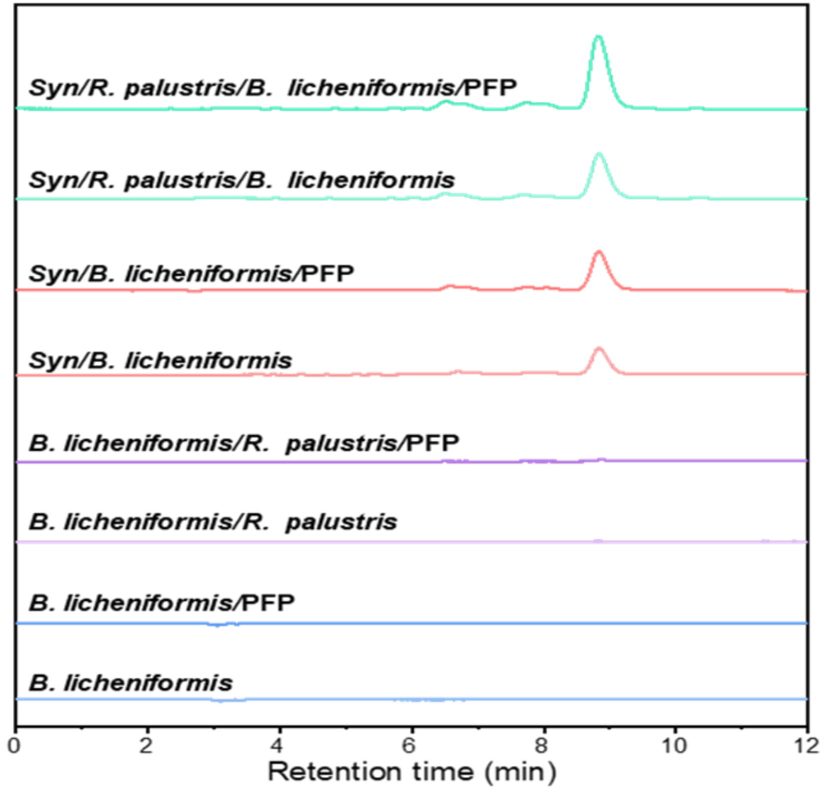


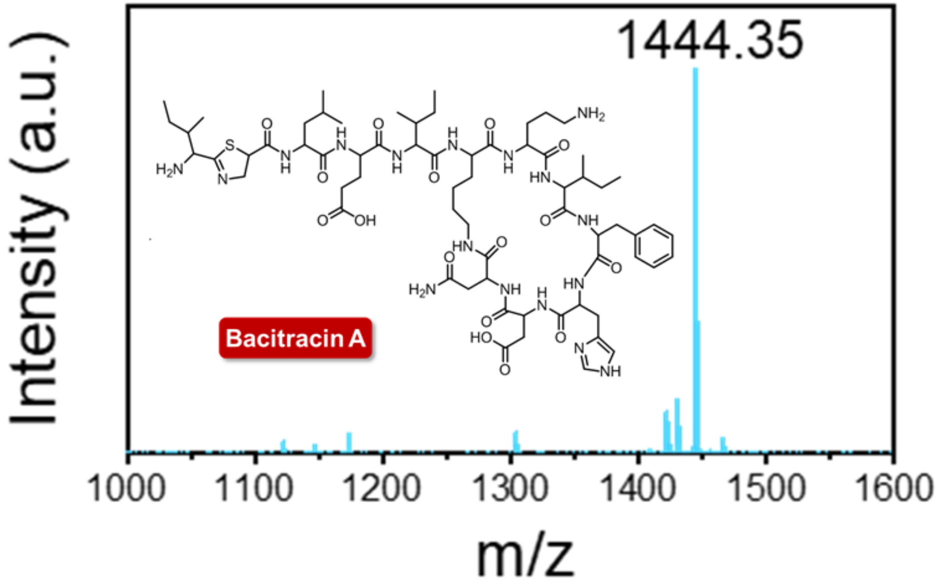
- Photoelectrons from Syn flow to B. licheniformis
- Photoelectrons from R. palustris flow to B. licheniformis

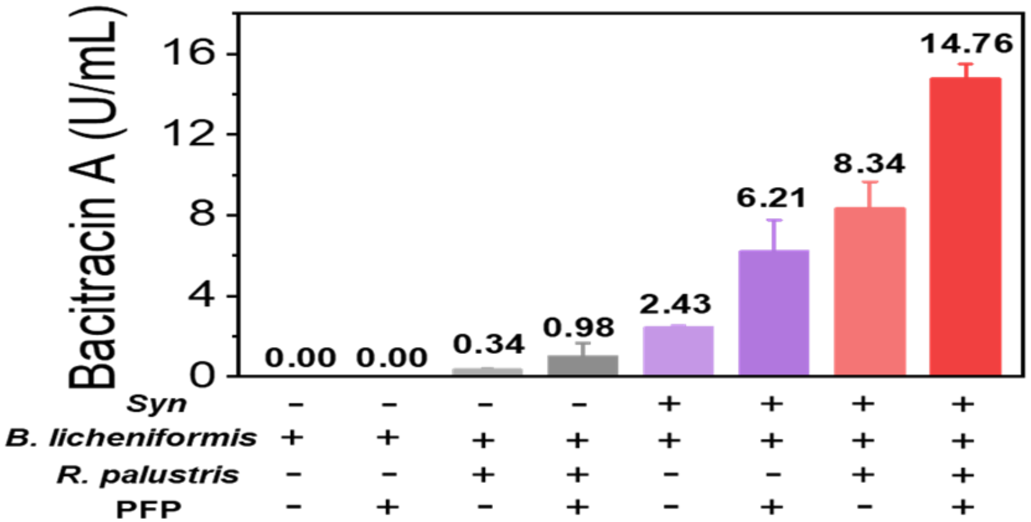


- PFP and compatible membrane proteins mediate electron transfer

Improved the Bacitracin A synthesis



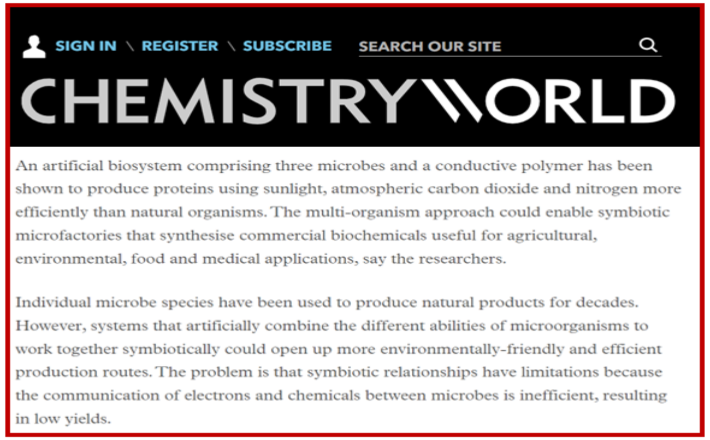




- Increased by 77 % and 138 % than Syn/R. palustris/B. licheniformis and Syn/B. Licheniformis/PFP

Summary and outlook

- We developed a novel biohybrid system based on panchromatic polymer dots–bacteria for photosynthetic CO2 reduction into acetic acid
- We constructed solar-powered multi-organism symbiont mimic system and created a new path to synthesize bio-functional polypeptides utilizing CO_2 and N_2 as carbon and nitrogen sources.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CHEMISTRY WORLD

An artificial biosystem comprising three microbes and a conductive polymer has been shown to produce proteins using sunlight, atmospheric carbon dioxide and nitrogen more efficiently than natural organisms. The multi-organism approach could enable symbiotic microfactories that synthesise commercial biochemicals useful for agricultural, environmental, food and medical applications, say the researchers.

Individual microbe species have been used to produce natural products for decades. However, systems that artificially combine the different abilities of microorganisms to work together symbiotically could open up more environmentally-friendly and efficient production routes. The problem is that symbiotic relationships have limitations because the communication of electrons and chemicals between microbes is inefficient, resulting in low yields.


XINHUANET

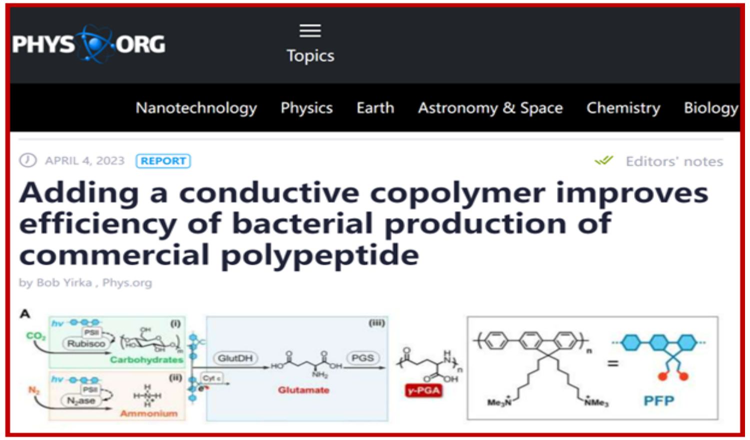
Artificial bacterial "factory" created to synthesize proteins more efficiently

Source: Xinhua Editor: huaxia 2023-03-17 11:55:30

BEIJING, March 17 (Xinhua) -- Chinese researchers have created a kind of artificial bacterial "factory" that uses solar power and airborne carbon dioxide and nitrogen to synthesize proteins essential for applications in agriculture, medicine and the environment.

While some organisms are capable of producing useful biological molecules, the industry requires a greater quantity of these molecules than what can be naturally generated by microbes.

One solution is to add biocompatible conductive polymers into the biosystem to improve photosynthesis and electron transfer between organisms.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APRIL 4, 2023 REPORT Editors' notes

Adding a conductive copolymer improves efficiency of bacterial production of commercial polypeptide

by Bob Yirka , Phys.org

Summary

- **Efficiency**
  Further development of high-performance photoelectronic materials compatible with biological components is essential to improve system efficiency.
- **Stability**
  Optimizing the material–microbe interface and exploring better biohybrid construction strategies are key to enhancing system stability.
- **Applicability**
  Expanding product scope toward higher-value chemicals and considering device integration and engineering design will promote practical application.

Acknowledgments

Group members

Prof. Shu Wang

Prof. Fengting Lv, Prof. Yiming Huang

Dr. Weijian Chen, Jiantao Lin, Junjie Chen…

Cooperative partner

Prof. Haining Tian, Prof. Xi Zhang,

Prof. Chengfen Xing, Prof. Lidong Li …

¥ NSFC、CAS、ICCAS

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